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14. ABSTRACT
A new type of infrared detector is designed and experimentally demonstrated, which uses "unipolar barriers" in the detector's epitaxial structure to block dark currents, while passing photocurrent. Varieties of these new detectors include nBn detectors and unipolar barrier photodiodes. In comparison to conventional photodiodes, dark current suppression by at least six orders of magnitude is demonstrated in both nBn and unipolar barrier photodiodes. The concepts are demonstrated in InAs-based materials, but are more generally applicable in other IR materials such as strained layer superlattice and HgCdTe.

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Introduction

Unipolar barriers are heterostructures that block the flow of one carrier type and pass the other carrier type. Unipolar barriers are alternatives to the more conventional barriers that use pn junctions and space charge regions, which are significant sources of dark current and noise in infrared detectors. Unipolar barriers can be made in either of two types: hole-blocking or electron-blocking barriers. Our work has concentrated on the type of unipolar barrier that blocks electrons and passes holes.

We have designed and constructed unipolar barriers using semiconductor heterojunctions that have large conduction band offsets and zero valence band offsets, as illustrated in figure 1. An example of such a heterojunction is InAs / $AlAs_{0.17}Sb_{0.83}$.

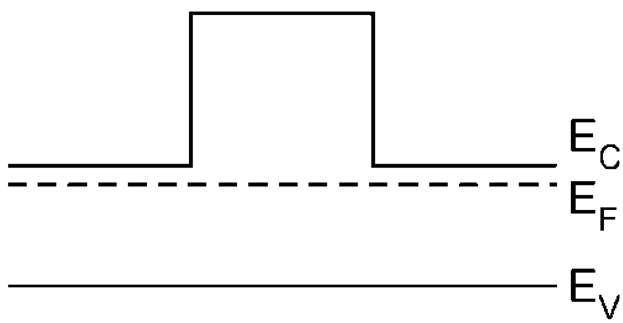

Fig.1. Band diagram of an electron-blocking, hole-passing unipolar barrier. The barrier consists of two different semiconductor materials which have equal valence band energies.

This work has used unipolar barriers in the epitaxial structures of otherwise-conventional IR detectors to achieve dramatic suppression of specific types of dark current components, while not interfering with photocurrents. We use InAs-based materials to demonstrate these unipolar barrier IR detector concepts, but they may also be implemented in most other common IR detector semiconductor material systems, such as InAsSb, strained layer superlattices, and HgCdTe. We have demonstrated that unipolar barriers can suppress dark currents by over six orders of magnitude.

The Concept

The currents that flow in photodetectors can be grouped into three categories, photocurrent caused by the IR source that is being detectors, dark current that flows whether or not there is any IR present, and background current resulting from the detector responding to the ambient IR background. All of these currents are sources of noise. The aim of this work, and much of IR detector development, is to decrease the dark current below the magnitude of background current, thereby creating BLIP (background limited infrared photodetection) operation – the best performance obtainable. Our work has produced increases in the maximum temperature of BLIP operation by 50 degrees K or more, thereby drastically reducing the cooling requirements of IR detectors.

The aim of this work is to insert unipolar barriers into photodetector epitaxial structures in such a way as to block components of dark current, while passing the flow of photocurrent. This is accomplished by identifying locations in the detector where the photocurrent is carried by holes, but dark current components are carried by electrons. Insertion of an electron-blocking / hole-passing unipolar barrier in such a location is very effective in improving detector performance.

Results

The simplest type of photodetector is a photoconductor, which consists of an n-type semiconductor with two ohmic contacts. When the photoconductor is biased for operation, a current flows through the device, which is its main component of dark current. This dark current can be very effectively suppressed via the use of a unipolar barrier. We have inserted unipolar barriers into photoconductors creating the so-called nBn detector, which suppresses dark currents by at least six orders of magnitude, down to undetectable levels, as shown in figure 2.

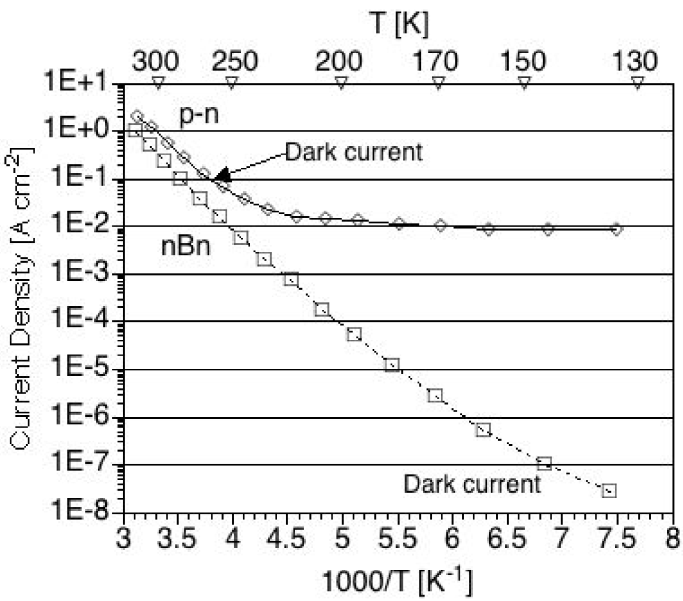

Fig. 2. Temperature dependence of dark current density of an nBn detector compared to a conventional pn photodiode. The unipolar barrier in the nBn can suppress dark current by over six orders of magnitude.

Additionally, we have inserted unipolar barriers into photodiodes. As shown in figure 3, the unipolar barrier can block surface leakage current, while allowing photocurrent to pass. It is important to note that this suppression of surface current is extremely effective, and does not require surface passivation treatments, which add complexity and cost to the processing of conventional devices.

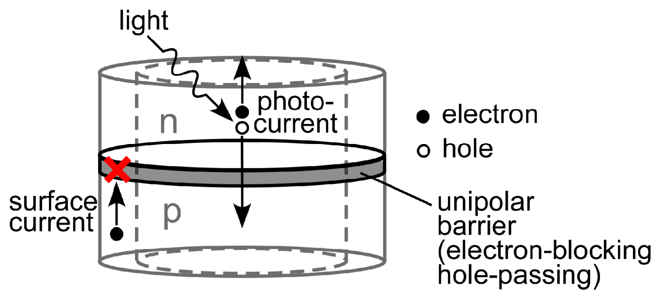

Figure 3. A unipolar barrier inserted into a pn photodiode can block surface leakage current without inhibiting the flow of photocurrent.

In addition to blocking surface leakage current, we have demonstrated that the unipolar barrier is also very effective in blocking the dark current components that originate in the pn junction, namely generation-recombination current, band-to-band tunneling current and trap-assisted tunneling current.

The benefit of this approach is reflected in improvement in the photodiode's R_oA (zero voltage differential resistance area product), a parameter that is inversely related to the detector's noise. As a result of this dark current suppression, unipolar barrier photodiodes exhibit R_oA values that are six orders of magnitude greater than those of conventional photodiodes, shown in figure 4.

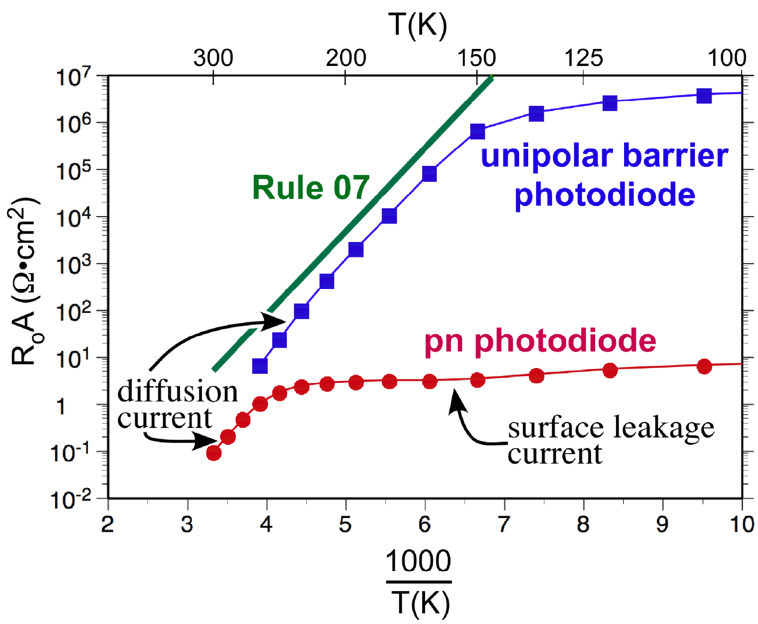

Fig. 4. Temperature dependence of the R_oA values for a conventional InAs photodiode and an InAs unipolar barrier photodiode. Also shown is Rule 07 [W.E. Tennant, D. Lee, M. Zandian, E. Piquette, and M. Carmody, Journal of Electronic Materials **37** (9), 1406 (2008)], which models the ideal performance of a photodiode. The use of a unipolar barrier can increase R_oA by as much as six orders of magnitude.

Finally, we present a general description of the use of unipolar barriers, showing explicitly which types of dark currents can be blocked and which types of dark currents cannot be blocked. The description relies on the spatial makeup of the dark currents, relative to that of the photocurrent. Surface leakage currents and space-charge-layer currents (g-r, band-to-band tunneling, defect-assisted tunneling) can be blocked; diffusion currents cannot be blocked.

Summary

The work has developed a revolutionary IR detector concept, the unipolar barrier detector to suppress dark current, and demonstrated its effectiveness in suppressing dark currents by six orders of magnitude. The concept has been widely adopted by the leading IR detector R&D groups in the country and has spawned a new field in IR detectors. At least one DoD contractor, Lockheed Martin, has already implemented these new types of IR detectors in its defense systems.